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PHYSICAL PROPERTIES OF SOME MINERAL AND ORGANIC SOILS OF THE PROVINCE OF QUEBEC[1]

BY W. F. OLIVER[2]

Abstract

The physical properties of 47 samples of various horizons of virgin and cultivated soils of varying organic content have been measured. These properties include loss on ignition, amount of clay, silt, and sand, moisture content at the sticky point, moisture taken up at 50% relative humidity, pore space, heat of wetting, volume expansion, maximum moisture taken up, index of texture, and apparent and absolute specific gravity. Correlation coefficients and indices of correlation have been determined together with the linear and curvilinear regressions giving the relations between these physical properties. These results show that with one exception the loss on ignition may be used as an independent variable to predict the other physical properties.

Introduction

The work presented here is an extension of a study of the physical properties of Quebec soils, carried on in this laboratory, to include some soils with high organic content. Previous work (6) has indicated that determinations of the organic matter (or loss on ignition) and clay content are necessary in order to predict the physical behaviour of the soils.

In the present investigation a large number of physical constants have been determined and the regression equations worked out for the soils. The measurements include data on the *A* horizon of 19 soils in which the organic matter varies from about 10% to that of the high organic soils of the "black muck" type.

Samples have been taken from both cultivated and virgin organic soils. Also, observations on lower horizons of the eight mineral soils are reported; thus altogether 47 sets of determinations have been made.

Experimental Procedure of Analysis

The methods of analysis employed have been adequately described elsewhere (6). In the mechanical analysis of the soils, the international pipette method (2) was used.

As the investigation was interrupted by war work, some of the measurements were repeated, particularly those involving judgment of the experimenter, to ensure that uniform technique was applied to all soils.

[1] *Manuscript received January 17, 1946.*

Contribution from the Department of Physics, Faculty of Agriculture of McGill University, Macdonald College, Que. Macdonald College Journal Series No. 214.

[2] *Assistant Professor of Physics.*

Experimental Results

Tables I and II contain the experimental observations and are in themselves self-explanatory. The values recorded in the tables are the averages of at

TABLE I

MECHANICAL ANALYSIS OF QUEBEC ORGANIC SOILS**

Location number	Horizon	Location	Stones, %	Coarse sand, %	Fine sand, %	*D* Silt, %	*C* Clay, %	*N* Moisture in air-dry soil, %	*B* Loss on ignition, %
1	A_1	½ mile N. of Frelighsberg	18.4	14.1	32.5	2. 6	15.8	3.8	15.24
	B_1	(Woodbridge loam—Ref. (4))	32.4	20.0	36.8	22.8	12.6	2.2	6.58
	B_2		38.4	23.7	40.4	19.4	13.5	1.4	4.53
	C		53.7	24.8	46.4	20.6	7.2	0.5	1.86
2	A_1	Frelighsberg	27.9	14.7	36.4	19.4	15.6	2.8	14.61
	B_1	(Woodbridge loam—Ref. (4))	34.9	22.5	39.8	17.7	13.2	2.2	7.70
	B_2		43.1	30.5	39.7	16.8	8.8	1.6	4.88
	C		48.6	26.2	41.0	20.7	9.5	0.6	1.96
3	A_0	1½ miles S. of Kingscroft	25.0	9.4	39.1	15.8	10.0	3.9	27.95
	A_2	(Greensboro loam—podsol—	13.3	14.6	54.8	22.7	6.3	0.5	1.72
	B_1	Ref. (1))	21.4	14.2	43.6	11.1	21.1	3.1	9.56
	B_2		17.9	16.7	47.9	18.3	9.6	1.8	5.85
	C		21.0	16.9	48.8	22.6	11.0	0.6	1.88
4	A_0	2½ miles S.E. of Kingscroft	12.0	11.8	44.8	16.4	9.3	3.1	19.42
	A_2	(Greensboro loam—podsol—	12.5	14.8	56.4	20.4	6.4	0.5	1.76
	B_1	Ref. (1))	10.0	15.2	47.9	9.2	21.4	2.3	7.66
	B_2		21.3	15.5	51.8	21.3	8.9	1.7	3.79
	C		28.6	17.2	49.0	21.1	11.8	0.6	1.76
5	A_0	2 miles W. of Ayer's Cliff	26.2	10.8	14.8	13.3	10.2	10.1	61.2
	A_2	(Ascot sandy loam—podsol—	15.1	18.4	44.2	25.0	9.2	0.9	1.86
	B_1	Ref. (1))	24.0	22.2	37.6	18.8	11.9	3.4	11.20
	B_2		38.1	24.5	38.1	18.7	11.2	2.3	7.79
	C		29.0	22.1	43.1	21.3	12.3	0.6	1.94
6	A_0	1½ miles W. of Ayer's Cliff	16.2	6.3	8.4	12.0	8.1	8.0	76.1
	A_2		18.5	23.2	39.2	24.8	9.2	1.0	2.68
	B_1		41.4	35.3	27.3	16.0	12.0	3.5	14.14
	B_2		29.2	30.4	33.7	19.8	11.5	1.6	5.24
	C		27.0	26.8	37.0	21.7	11.8	0.7	2.59
7	A_1	6 miles S.E. of Cowansville	26.7	10.4	37.9	20.4	14.9	5.5	16.54
	B_1	(podsolic)	35.8	17.4	37.5	20.1	14.5	4.7	10.87
	B_2		25.5	15.0	39.6	20.5	14.5	4.0	12.54
	C		44.0	21.4	46.4	13.5	12.4	3.9	7.56
8	A_1	¼ mile W. of Location 7	22.4	13.2	31.0	27.3	14.5	3.9	14.39
	B_1	(podsolic)	28.1	25.6	25.6	24.6	14.4	3.4	9.54
	B_2		23.2	18.6	33.4	26.2	14.9	2.0	6.56
	C		76.8	13.1	39.5	31.4	13.8	0.9	2.40
9†	A	2 miles N.W. of St. Martin	0.2	1.7	5.7	18.9	16.8	12.2	67.6
10†	A	¼ mile N.W. of St. Martin	3.2	3.9	4.5	16.8	8.5	17.6	84.2
11*†	A	¼ mile N.W. of St. Martin	0.8	2.2	4.4	18.8	11.3	17.9	77.1
12†	A	2½ miles N. of Dorval	4.8	2.0	5.4	10.8	15.5	15.0	74.4
13*†	A	2 miles N. of Dorval	6.2	1.8	10.5	20.9	25.4	10.9	49.5
14*†	A	2 miles S.E. of Saraguayville	0.0	1.6	3.8	15.2	15.5	20.6	74.9
15†	A	2 miles S.E. of Saraguayville	0.4	0.8	2.3	15.9	14.1	18.8	80.6
16†	A	Macdonald College	5.0	2.4	5.7	12.8	27.5	13.7	60.6
17*†	A	Macdonald College	1.7	2.3	5.7	16.8	14.4	16.0	71.4
18*†	A	Macdonald College	2.0	3.0	4.7	16.0	10.5	15.8	82.5
19*†	A	Macdonald College	1.0	4.8	22.5	15.2	11.4	8.6	56.7

* *Cultivated soils.*

** *These soils are free of calcium carbonate.*

† *Organic soils—muck, Ref. (5).*

least duplicate and in some cases quadruplicate measurements. For reasons of consistency, the terminology introduced in the earlier work is used in this paper. The evaluation of the percentage of organic carbon has not been carried out for all samples, and so is not included in the tables.

TABLE II

PHYSICAL ANALYSIS OF QUEBEC ORGANIC SOILS

Location	Horizon	*E* Moisture at sticky point, %	*F* Moisture at 50% relative humidity, %	*G* Pore space, %	*H* Heat of wetting, cal./gm. %	*J* Volume expansion, %	*K* Maximum moisture taken up, %	*M* Index of texture	*P* Apparent specific gravity	*Q* Absolute specific gravity
1	A_1	55.9	3.95	62.8	6.68	18.2	86.0	46.6	0.90	2.01
	B_1	30.1	2.68	56.4	3.90	15.9	60.0	18.7	1.12	2.25
	B_2	23.1	1.94	50.7	3.22	13.7	42.3	10.3	1.37	2.42
	C	14.6	0.52	38.8	0.79	4.0	27.2	0.3	1.59	2.51
2	A_1	44.9	3.62	61.4	5.78	19.6	78.8	34.7	0.96	2.04
	B_1	29.9	2.93	56.4	4.82	16.4	58.3	17.5	1.18	2.28
	B_2	22.4	1.80	50.4	2.47	13.4	43.5	8.3	1.36	2.39
	C	13.6	0.62	40.0	1.20	3.8	27.0	0.2	1.57	2.51
3	A_0	60.8	5.58	69.1	9.61	27.1	136.5	51.1	0.70	1.70
	A_2	18.4	0.69	43.8	1.40	8.1	34.0	4.5	1.46	2.39
	B_1	33.6	3.80	58.8	5.01	4.9	66.4	22.0	1.08	2.25
	B_2	25.0	2.24	52.8	3.47	16.0	51.9	12.1	1.25	2.26
	C	13.9	0.75	40.8	0.92	9.0	29.2	0.8	1.57	2.46
4	A_0	56.0	3.94	67.2	6.18	25.7	103.5	44.7	0.86	2.02
	A_2	19.2	0.62	43.6	0.87	7.2	34.9	5.0	1.44	2.38
	B_1	32.1	2.70	57.8	4.54	15.6	62.0	19.5	1.13	2.27
	B_2	21.2	1.46	49.8	1.82	11.2	43.6	7.9	1.32	2.36
	C	13.4	0.76	42.0	1.35	6.8	31.8	0.2	1.52	2.46
5	A_0	138.4	9.63	77.2	19.44	30.5	208.2	133.3	0.49	1.44
	A_2	19.3	1.18	45 8	2.19	7.0	36.4	6.8	1.39	2.38
	B_1	32.5	4.20	56.4	5.94	15.8	61.2	20.5	1.13	2.18
	B_2	26.1	2.76	51.8	4.46	14.2	50.2	13.6	1.24	2.21
	C	12.3	0.62	38.4	1.01	5.0	26.2	0.0	1.56	2.52
6	A_0	201.0	12.76	78.4	22.50	54.5	258.8	198.0	0.46	1.20
	A_2	22.1	1.37	48.5	1.81	4.4	52.1	9.6	1.26	2.32
	B_1	38.7	4.48	59.0	7.54	13.9	74.0	26.2	1.05	2.18
	B_2	23.7	2.08	53.0	2.64	12.3	49.0	10.9	1.28	2.39
	C	14.0	0.96	41.0	1.48	1.9	29.5	1.2	1.50	2.47
7	A_1	56.5	5.28	65.2	8.06	19.9	96.6	46.8	0.84	1.97
	B_1	41.2	4.28	61.4	6.34	17.2	81.0	30.2	0.98	2.09
	B_2	37.4	5.16	62.3	6.60	18.5	76.7	26.5	1.04	2.18
	C	27.1	3.92	55.0	5.10	15.4	63.7	13.5	1.25	2.28
8	A_1	39.5	4.29	61.9	6.88	8.3	79.4	30.7	0.88	2.07
	B_1	31.5	3.78	59.4	5.84	12.4	68.5	21.3	1.03	2.20
	B_2	27.4	2.59	56.6	3.65	13.8	65.6	17.0	1.14	2.30
	C	15.4	1.06	46.5	1.66	0.5	36.4	3.9	1.18	2.42
9	A	158.5	15.0	76.4	25.9	70.0	175	150.3	.684	1.50
10	A	234.5	18.3	77.4	35.4	82.7	237	233.7	.568	1.35
11	A	171.4	16.9	78.5	34.3	73.7	187	170.6	.654	1.43
12	A	144.8	14.4	80.0	29.0	102.8	190	143.9	.787	1.63
13	A	101.0	10.4	73.8	20.7	74.9	132	100.8	.888	1.71
14	A	157.1	17.6	74.4	31.5	76.7	222	157.0	.686	1.28
15	A	171.7	16.8	74.8	31.5	109.6	245	71.0	.750	1.21
16	A	124.2	12.0	72.4	21.0	94.1	191	123.8	.820	1.37
17	A	161.7	14.6	76.0	30.5	69.2	235	161.3	.672	1.35
18	A	161.7	13.9	76.2	28.2	63.4	242	161.2	.581	1.30
19	A	103.3	9.0	70.4	15.8	41.8	214	102.7	.688	1.50

Scatter diagrams between the soil variables, taking them two at a time, revealed that there were a large number of linear relations between the soil variables, but in a number of cases (e.g., Figs. 1-6) linear relations could not be used for the wide range of organic soils studied in this investigation. However, it was possible to find linear relations between functions of these variables, and hence the ordinary methods of linear correlation analysis could be applied.

It might be contended that in this work all variables were subject to random error and therefore the method of Wald (7) for fitting straight lines was to be preferred. In that method the sum of the squares of the departures of each observation perpendicular to the fitted lines was to be made a minimum. However, this investigation indicated that generally the loss on ignition was sufficient to predict the behaviour of the soils and as this could be measured with precision, then the usual procedure of minimizing the sum of the squares of the "vertical" departures from the fitted line could be used.

TABLE III

a. GROSS LINEAR CORRELATION COEFFICIENTS BETWEEN SOIL "CONSTANTS" OF 47 QUEBEC SOILS

b. GROSS CORRELATION COEFFICIENTS BETWEEN FUNCTIONS OF SOIL "CONSTANTS" OF 47 QUEBEC SOILS

B—Loss on ignition, %
C—Clay, %
D—Silt, %
E—Moisture content at the sticky point, %
F—Moisture taken up at 50% relative humidity, %
G—Pore space, %
H—Heat of wetting, cal./gm.
J—Volume expansion, %
K—Maximum moisture taken up, %
M—Index of texture
P—Apparent specific gravity
Q—True specific gravity

Significant, prob. = 0.05; $r > 0.288$

Highly significant, prob. = 0.01; $r > 0.372$

(*a*)

—	*C*	*D*	*E*	*F*	*H*	*J*	*K*	*M*	1/*Q*
B	+ .1932	− .5017	+ .9825	+ .9786*	+ .9822	+ .9274	+ .9766	+ .9862	+.9703
C	+1	− .2160	+ .1422	+ .2575	+ .2291	+ .3706	+ .1763	+ .2030	+.1832
D		+1	− .4815	− .4774	− .4620	− .4986	− .5289	+ .5276	+.4388
E			+1	+ .9701	+ .9710	+ .8959	+ .9641	+ .9995	+.9609
F				+1	+ .9942	+ .9484	+ .9457	+ .9729	+.9444
H					+1	+ .9391	+ .9407	+ .9748	+.9375
J						+1	+ .5199	+ .9028	+.8817
K							+1	+ .9682	+.9863
M								+1	+.9644

* *First approximation.*

(*b*)

—	Log *B**	Log *C*	Log *D*	Log *E*	Log *F*	Log *H*	Log *J*	Log *K*	Log *M*	Log 1/*Q*	Log *P*
G	+.9941	+.3708	−.5169	+.9850	+.9880	+.9899	+.8901	+.9910	+.9513	+.8324	− .9587
Log *P*	−.9383	−.9170	+.4388	−.9494	−.9079	−.9171	−.7156	−.9597	−.8572	−.8469	+1

* *Common logarithms are used throughout this paper.*

Table III*a* contains the simple or gross correlation coefficients for those cases in which the graphs showing the relations between the variables indicated linearity. Table III*b* gives the gross correlation coefficients between functions of those variables in which the ordinary scatter diagram exhibited curvilinearity. Since the reciprocal of the absolute specific gravity has been found to yield linear relations with the other soil variables (exclusive of pore space, *G*), the correlations with these other variables have been included in Table III*a* solely for convenience in tabulation. The linear correlation coefficients between functions of the variables are usually called the indices of correlation between the variables, the nature of the curve in each case being specified. Table IV lists the partial correlation coefficients as determined by the Doolittle method (3).

TABLE IV

PARTIAL LINEAR CORRELATION COEFFICIENTS

—	*E*	*F*	*H*	*J*	*K*	*M*	1/*Q*
B	+.979	+.975	+.979	+.922	+.969	+.983	+.961
C	−.253	+.354	+.247	+.515	−.087	+.048	−.022
D	+.035	+.133	+.227	−.036	+.220	+.221	−.025

Discussion of Results

The results presented in Tables III and IV indicated that the loss on ignition was the main factor controlling the physical properties of these soils. In no case did silt yield a significant effect. Furthermore, only in three cases: viz., moisture taken up at 50% relative humidity, *F;* pore space, *G;* and volume expansion, *J*, did clay apparently make any contribution to the physical behaviour of the soils, and of these there was only one that yielded a highly significant partial correlation coefficient, viz., $r_{JC \cdot BD} = +.515$. In addition, the partial correlation coefficients between the different dependent variables and loss on ignition (the independent variable) were, except for one case, all greater than + .96. It would then seem that for this group of soils the loss on ignition, and the loss on ignition alone, could be used to predict their physical properties.

The small effect of clay on the physical behaviour seems to be a characteristic of Quebec soils. Rowles (6) has found that for a number of Quebec soils the amount of clay is relatively small and therefore it does not play a prominent part in determining the character of the soil, as it does in other localities. The present investigation shows that for soils with a relatively high organic content, the amount of clay, with one exception, makes no significant contribution to the behaviour of these soils.

Further evidence to substantiate this conclusion follows in more detail. Table V presents the regression equations (Equations (1 to 9)) using loss on ignition, *B*, as independent variable. The gross correlation coefficients corrected for the number of samples are also included in Table V.

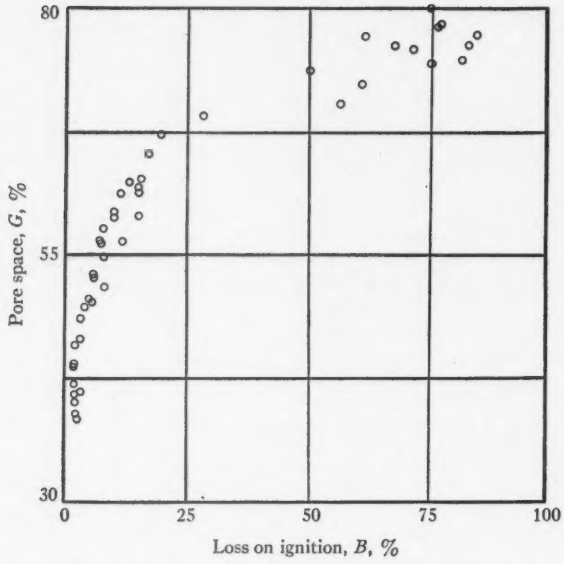

FIG. 1. *G–B scatter diagram shown on arithmetical scales.*

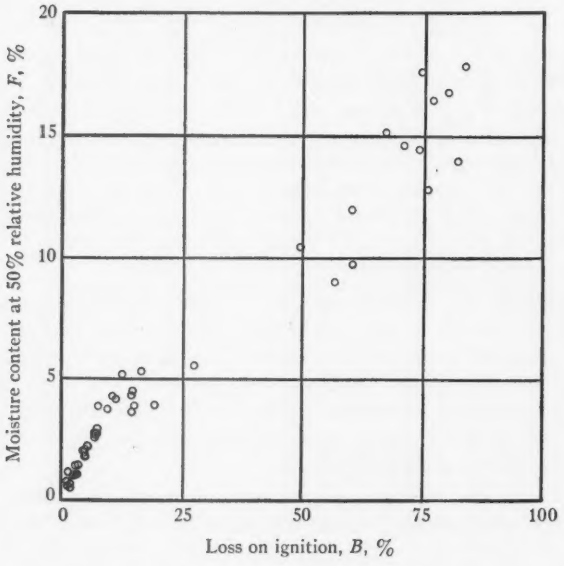

FIG. 2. *F–B scatter diagram.*

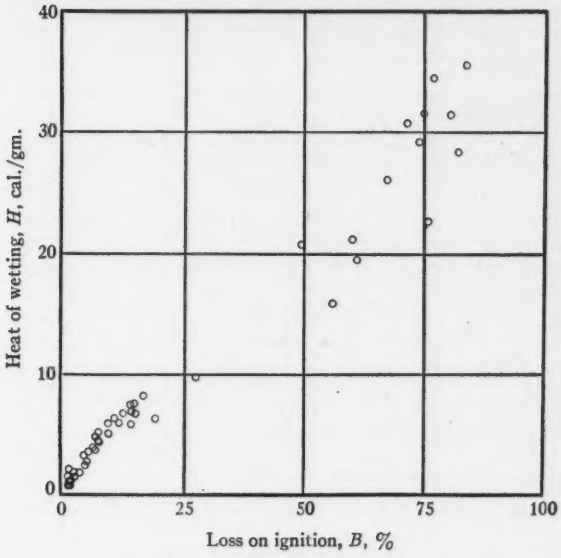

FIG. 3. *H–B scatter diagram.*

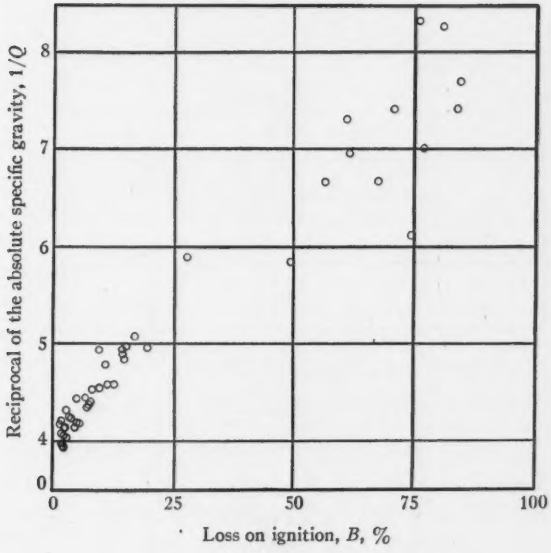

FIG. 4. *1/Q–B scatter diagram.*

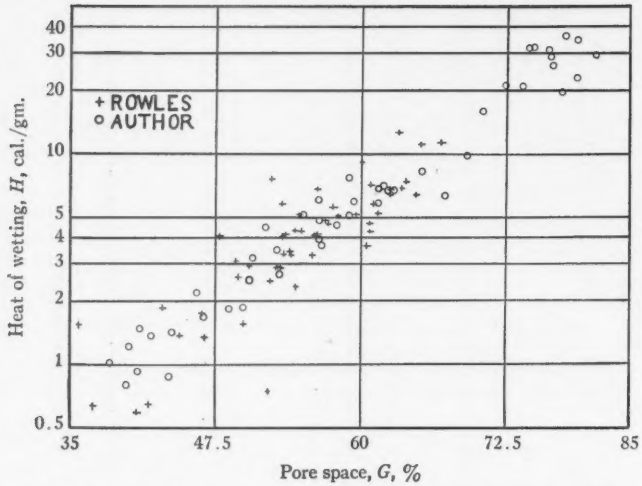

FIG. 5. *H–G scatter diagram of combined results from this laboratory on semilog rulings.*

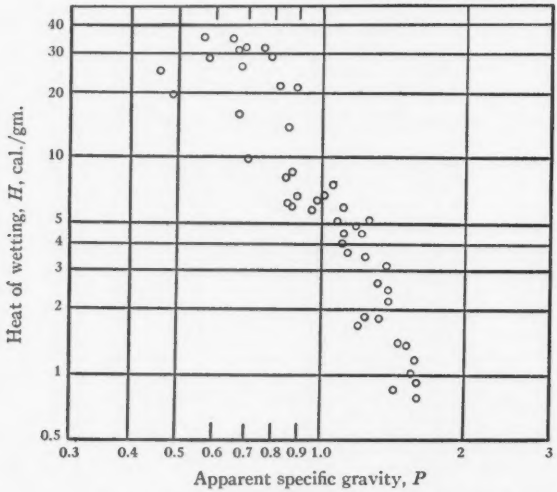

FIG. 6. *H–P scatter diagram shown on log-log rulings.*

Besides these equations, the regressions using loss on ignition, clay, and silt as independent variables have been worked out for a number of cases and are given in Table VI. For each of these the multiple correlation coefficient $\bar{R}_{X \cdot B\,CD}$ has been calculated and included in the table. The difference between the multiple correlation coefficient $\bar{R}_{X \cdot B\,CD}$ and the gross correlation

TABLE V

REGRESSION EQUATIONS FOR SOIL PROPERTIES IN TERMS OF LOSS ON IGNITION, B

Equation No.	Regression equation	$\bar{r}$ *
1	$E = 12.47 + 2.06\ B$	.9821
2	$F = 1.10 + 0.184\ B$	.9781
3	$G = 36.67 + 21.50\ \text{Log}\ B$	.9938
4	$H = 1.04 + 0.365\ B$	.9818
5	$J = 5.33 + 0.947\ B$	.9259
6	$K = 37.54 + 2.48\ B$	.9761
7	$M = -0.75 + 2.22\ B$	.9859
8	$\text{Log}\ P = 0.249 - 0.233\ \text{Log}\ B$	.9350
9	$1/Q = 0.408 + 0.00445\ B$	.9696
10	$F = 1.75 + 0.175\ B - \frac{2.35}{B}$	$\bar{\rho} = .9800$

* $\bar{r}$ *corrected for the size of sample (47).*

TABLE VI

REGRESSION EQUATIONS FOR PHYSICAL PROPERTIES OF SOME QUEBEC SOILS

Equation No.	Regression equation	$\bar{R}$ *
1	$E = 2.08\ B - 0.685\ C + 0.100\ D + 18.92$	.9822
2	$F = 0.184\ B + 0.095\ C + 0.037\ D - 0.791$	.9786
3	$H = 0.369\ B + 0.117\ C + 0.117\ D - 2.79$	.9823
4	$J = 0.898\ B + 1.356\ C - 0.086\ D - 9.21$	.9428
5	$K = 2.32\ B - 0.325\ C - 0.874\ D + 62.28$	.9779
6	$M = 2.17\ B + 0.117\ C - 0.620\ D + 10.86$	.9876
7	$1/Q = 0.044\ B - 0.000167\ C - 0.000209\ D - 0.5817$	.9717

* $\bar{R}_{X\ .\ B\ CD}$ = *the multiple correlation coefficient corrected for the size of the sample (47).*
X . *represents E. F. . . . . in turn.*

coefficient, $\bar{r}_{XB}$, was tested in each case to determine whether any significant contribution had been made by the use of the two additional independent variables, clay and silt, or by one of them. This provided a check on the results indicated by the significance or the non-significance of the partial correlation coefficients.

Moisture at the Sticky Point, E; Maximum Moisture Taken Up, K; Index of Texture, M.

Experiments showed that there were linear relations between each of these variables, in turn, with the loss of ignition. Furthermore, the amount of silt and clay present in these soils did not seem to affect significantly any measurement involving high moisture content, such as E, K, or M.

Moisture Taken Up at 50% Relative Humidity, F

As a first approximation the correlation between the moisture taken up at 50% relativity humidity and loss on ignition was assumed to be linear. On this assumption, the gross correlation r_{FB} . was + .9786, while the partial

correlation coefficient $r_{FB \cdot CD}$ was + .975, $r_{FC \cdot BD}$ was + .354 and $r_{FD \cdot BC}$ was + .133. This meant that no advantage was attained from using silt and that a significant but not a highly significant effect was obtained by the addition of clay as an independent variable.

The scatter diagram of Fig. 2 shows that a linear *F-B* curve is only an approximation and that a considerable departure from linearity for low values of *B* occurs. The nature of the graph indicates that a curve of the type

$$F = a + b\,B + \frac{c}{B} \qquad (a, b, c, \text{ are constants})$$

may be a better fit than a straight line. Equation (10) of Table V represents the least square curve with an index of correlation $\bar{\rho}_{FB} = .9800$. That this curve yields a significantly better fit to the observations is shown by the analysis of variance as carried out in Table VII.

TABLE VII

ANALYSIS OF VARIANCE TO TEST THE DEPARTURE FROM LINEARITY OF THE *F-B* RELATION

Linear correlation coefficient $\bar{r}_{FB} = .9781$

Index of correlation $\bar{\rho}_{FB} = .9800$, for Curve $F = 1.75 + 0.175\,B - \frac{2.35}{B}$

	Degrees of freedom	Variance	*F* observed	*F* 5% point
Explained by st. line $\bar{r}^2_{FB} = .9567$				
Additional explained by $\bar{\rho}^2_{FB} - \bar{r}^2_{FB} = .0037$	1	.0037	4.11	4.06
Error $1 - \bar{\rho}^2_{FB} = .0396$	44	.00090		

The introduction of curvilinearity into the *F-B* relation meant that the partial correlation coefficients $r_{FB \cdot CD}$ and $r_{FC \cdot BD}$ should be replaced by the respective partial indices of correlation. It would be expected that the partial indices of correlation would change, with $r_{FB \cdot CD}$ increasing and $r_{FC \cdot BD}$ decreasing — the latter decreasing perhaps below the value required for significance. Since the evaluation of the partial indices of correlation involve a great deal of arithmetical labour, it seemed that the information required could be elicited by deriving the multiple relation, using *B* and *C* as independent variables. *D* was omitted for it made no significant contribution to the physical behaviour of these soils. The multiple relation involving the clay content, *C*, as an additional independent variable was expressible by the equation

$$F = 0.747 + 0.175\,B - \frac{1.73}{B} + 0.0688\,C$$

with index of multiple correlation $\bar{\rho}_{F \cdot CB}$, equal to .9809. This latter value as shown by the analysis of variance was not significantly greater than the simpler index of correlation $\bar{\rho}_{FB} = .9800$ given beside Equation (10) of

Table V. Consequently it would seem that the clay content of these soils was not a significant factor in the determination of the hygroscopic properties of the soils studied.

Pore Space, G

All graphs involving pore space, G, showed marked curvature on ordinary arithmetical scales. The curves indicated a logarithmic character; when semilogarithmic paper was used with pore space plotted on the arithmetical axis, linear curves could be drawn for all the resulting scatter diagrams.

While it seemed necessary to express pore space as a logarithmic function of B (or E, or F, etc.) to cover the complete range of these soils, linear relations could be used for soils in which the loss on ignition exceeded 30% and for soils in which the loss on ignition came within the range (1 to 5%). This, of course, was to be expected from the nature of the logarithmic relations. In such cases where the pore space was determined as a linear function of the loss on ignition, the following equations were derived:

$$G = 65.2 + 0.151\ B \quad \text{for } 30\% < B < 90\%$$
$$G = 36.2 + 3.20\ \ B \quad \text{for } 1\% < B < 5\%$$

Similar linear relations between pore space and the other variables could be obtained easily from the data in Tables I and II.

In addition it should be pointed out that while the index of correlation ρ_{GC} (= .3708), from Table III*b*, suggests that clay may have some influence on the pore space, the very high index of correlation $\bar{\rho}_{GB}$ (= .9938), from Table V, would indicate that its effect is questionable. Calculation of the multiple relation employing B and C as independent variables yields the equation:

$$G = 36.52 + 21.47 \log B + 0.169 \log C$$

with the index of multiple correlation equal to .9945. This value is not significantly different from the simple index of correlation between pore space and loss on ignition. This confirmed the conclusion that the clay content of these soils has little effect on the value of the pore space.

Heat of Wetting, H

The heat of wetting was very closely associated with the loss on ignition but did not seem to be influenced by either the percentage clay or the percentage silt. The *H-B* curve showed a tendency to depart from a straight line; the equation of the curve represented by

$$H = 1.41 + 0.360\ B - \frac{1.36}{B}$$

seemed to fit the points of the graph better. However, the analysis of variance indicated that this departure from the straight line represented by Equation (4) of Table V was not significant.

Volume Expansion, J

While a linear relation between the volume expansion and the loss on ignition was found to exist, the highly significant partial correlation coefficient $r_{JC \cdot BD}$ (= .515) indicated that clay did affect the volume expansion. Evaluation of the multiple correlation coefficients when two (B, D) and three (B, C, D) independent variables were used confirmed the conclusion that the volume expansion could be determined from the loss on ignition and clay content, the silt having no appreciable effect. The regression equation is given by:

$$J = 0.904\,B + 1.37\,C - 11.14$$

Apparent and Absolute Specific Gravity, P, Q

When either the apparent or the absolute specific gravity was plotted against the other variables, one at a time, curvilinear relations were indicated. Logarithmic paper for the curves involving apparent specific gravity proved useful, yielding linear graphs. Scatter diagrams between the reciprocal of the absolute specific gravity and any one of the other variables exhibited linearity. Finally, in neither case was clay or silt effective.

Choice of Independent Variables

The results above demonstrated that if a single quantity was to be used to deduce quantitatively the physical behaviour of the soils under investigation, the loss on ignition was suitable. Yet other choices of the highly correlated soil "constants" might be made as independent variable. One, in particular, viz., apparent specific gravity, P, might be suitable at times for determining the trend of the physical soil properties, largely because of its ease of measurement. However, the regression equations with P as independent variable would yield less accurate information than that based on loss on ignition. Nevertheless, wherever rough estimates of the soil properties would suffice, the equations of Table VIII would be of use.

TABLE VIII

REGRESSION EQUATIONS FOR SOIL PROPERTIES IN TERMS OF APPARENT SPECIFIC GRAVITY, P

Equation No.	Regression equation
1	$\log B = 1.07 - 3.79 \log P$
2	$\log E = 1.64 - 2.54 \log P$
3	$\log F = 0.551 - 2.93 \log P$
4	$G = 59.7 - 83.7 \log P$
5	$\log H = 0.763 - 3.16 \log P$
6	$\log J = 1.25 - 2.44 \log P$
7	$\log K = 1.90 - 2.09 \log P$
8	$\log M = 1.28 - 0.509 \log P$
9	$\log 1/Q = -0.249 - 0.653 \log P$

Virgin and Cultivated Organic Soils with High Loss on Ignition

In the above work, the data for virgin and cultivated soils were considered together. This fact appeared possible from the scatter diagrams but the analysis of covariance provides a definite check on this as illustrated for the regression of moisture at the sticky point, E, with the loss on ignition, B, in Table IX.

TABLE IX

TEST OF HETEROGENEITY OF REGRESSION BETWEEN VIRGIN AND CULTIVATED ORGANIC SOILS

—	Degrees of freedom	$\Sigma(B-\bar{B})^2$	$\Sigma(B-\bar{B})\ (E-\bar{E})$*	$\Sigma(E-\bar{E})^2$	b_{BE}	$b_{BE}\Sigma(B-\bar{B})(E-\bar{E})$	$\Sigma(E-\bar{E})^2$ corrected	Degrees of freedom
Virgin	7	2221	5931	18971	2.670	15836	3135	6
Cultivated	5	821	1917	5044	2.335	4476	568	4
Total	12	3042	7848	24015	2.580	20248	3777	11

—	Degrees of freedom	$\Sigma(E-\bar{E})^2$ corrected	Variance	F–value	F, 5% point
Total	11	3777			
Types	10	3703	370.3	.20	4.96
Difference	1	74	74		

* $\bar{E}$ = *average* E. $\bar{B}$ = *average* B.

The results in this table have been based on the 14 samples of which $B > 25\%$. It is obvious from the F-value (variance ratio) that there is no evidence of significant heterogeneity of regression between virgin and cultivated soils.

Comparison with Earlier Work

On comparing the results of Rowles (6) with those of the present work there appears to be general agreement between both sets of data. Fig. 5 represents graphically the combined data for heat of wetting vs. pore space.

The work of Rowles included various types of soils, but most of the samples were relatively low in organic matter; the few that contained an appreciable amount of organic matter indicated such small departures from linear relations that the use of the more involved curvilinear correlation analysis was not warranted. However, it was interesting to see how well his results fitted the more general relations given here. The earlier work indicated that clay influences the physical behaviour of the virgin soils of Quebec slightly more than was shown in the present investigation, but this should be expected for soils of lower organic content. The combined evidence indicated, however, that the organic content (or loss on ignition) was the predominant factor governing the behaviour of these soils, and that clay had to be relegated to a secondary place.

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